NEW APPROACH ON THE DESIGN AND EXECUTION OF ROAD INFRASTRUCTURES BASED ON EFFICIENT AND ENVIRONMENTAL EFFICIENCY AND ECOLOGICAL TECHNOLOGIES OF ENZYMATIC COMPOSITION AND STABILIZATION

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Rezumat. *Lucrarea detaliază o tehnologie neconvențională de realizare a infrastructurilor rutiere, cu implicații încă din faza de realizare a proiectului tehnic. Pentru structura rutieră, stabilizarea stratului de bază cu soluții enzimatice are următoarele avantaje: îmbunătăţeşte structura solului suficient de mult, pentru a realiza economii confirmate mai mari de 25% din costurile de construcţie de drumuri împietruite; întăreşte structura rutieră de autostrăzi, care au nevoie de reasfaltare şi elimină necesitatea de a îndepărta şi arunca asfaltul vechi. Reciclarea şi stabilizarea structurii rutiere creşte durabilitatea asfaltului de două până la trei ori. Prin aplicarea tehnologiei se reduce costul de achiziționare şi transport al materialelor de construcție pentru recondiționarea drumurilor, prin refolosirea materialelor in-situ, modernizarea şi ameliorarea solurilor existente.*

Abstract. *The paper details an unconventional technology for the realization of road infrastructure, with implications from the technical project stage. For the road structure, the stabilization of the base layer with enzymatic solutions has the following advantages: it improves the soil structure sufficiently long to achieve more than 25% of the costs of building hardened roads; strengthens the motorway road structure, which needs reassembly and eliminates the need to remove and discard old asphalt. Recycling and stabilizing the road structure increases the durability of the asphalt from two to three times. By applying technology it reduces the cost of purchasing and transporting construction materials for road rehabilitation, reuse of in-situ materials and modernization and improvement of the existing soils.*

Keywords: road infrastructure design, soil stabilization, enzyme.

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The challenges of the new wave of technological innovations and new building materials have not stayed away from the area of road design/construction. If technology has been upgraded much faster to market requirements and to the needs of builders, it has come to the designers to align themselves with the new requirements and problems that have arisen in this area. This upgrading came in the first wave in the form of software that adjusts your project in real time (CIVIL 3D, WindevRO, Calderom, etc.), the second wave came from laboratories, more precisely the marketing of unconventional products - which are a true copy of nature, such as the enzyme solution PERMA-ZYME 11X. The impact of these studies made by American researchers, A.R Tolleson, E. Mahdavian, F.M Shatnawi, N.E. Harman, has revolutionized the whole area of road construction. Through this article we aim to present and make a parallel with the classic design / construction of roads.

1. Road Design and Execution – Establishing the Project Management

In order to understand the steps leading to the construction of a road, and to understand the whole project implementation system, we will make a brief review of them.

- Phase 1: Technical expertise, the Technical Solution of Road Structure (Classical Solution / Unconventional Solution with Enzymatic Solution) is established.
- Phase 2: Feasibility Study, Building Approval, and Approval Documentation, Technical Opinions - technical and economic indicators are established.
- Phase 3: Technical Project and Execution Details, Building Approval Documentation - Preparing technical documentation after which the project will be implemented.
- Phase 4: Implementation of the project.

According to the data from I.N.S. in Romania there are 86,099 km, of which 17.6% D.N., 35.1% D.J., 33.3% D.C., 0.9% Highways. Of this total 35% are land and ballast roads.

In 2010, the World Bank commissioned a report that tracked the state of the Romanian infrastructure, namely the deficit of kilometres relative to the country and population. The result was desolate, as Romania needs 1 million kilometres of road to meet the basic needs of her citizens.

From this increasingly acute need, it has been attempted to find unconventional enzyme solutions. The enzyme analyzed by this article is Perma-zyme 11x, which can significantly reduce this km deficit by country through large-scale deployment (connecting roads, communal roads, county, forest, streets).

2. Short Presentation of Enzymatic Stabilization

Stabilization is the method of soil improvement by adding substances of a different nature to stabilized material (for example, one cannot talk about stabilization of sand with clay). The most commonly used stabilizing method is that of using hydraulic binders.

Cement is generally more expensive, it is used only in special situations. Chalk is the most commonly used binder for stabilizing the foundation bed (platform layer) or platforms, this material also has the advantage that in the "unstained" state the moisture of the soil decreases with the need for hydration water. When the chalk is introduced into a wet earth, it ionizes and produces calcium cations that can change loads with the clay structure. The calcium cation interacts with sodium and potassium in the clay structure as chemical stabilizers change ions between them. Because calcium cation has a large size, it cannot move too much inside the clay structure; therefore, in order to obtain optimal results with this type of stabilizer, a mixture is required and considered as suitable. The high ionization energy of calcium attracts clayey molecules, releasing excess water and breaking the clay network.

The presence of chalk increases the pH value of the earth. In the case of a high pH value, the aluminium and silicon are released from the puzzolanic stabilizers and the clay structure. The thus released aluminium and silicon molecules react irreversibly with calcium ions, forming alumina calcium silicates that are similar as to properties with Portland cement. These calcium silicates have negative charges that attract ionized water dipoles and form a network of hydration bonds that strengthen the structure of the earth.

Besides the relatively high cost of the binder, the major disadvantage of stabilizing with chalk is to obtain a rigid structure that once destroyed can no longer self-repair. Hydraulic binders improve the structural cohesion of the material over the ionic one, although the material finally obtained has a particularly high load bearing capacity.

It can be concluded from that the stabilization with hydraulic binders is the ideal solution for upper class roads, where there is a cement or asphalt cement superstructure over the mould layer, while for communal roads the solution is inadequate from the point of view of both time and price behaviours.

For operational and communal roads the most widespread solution today is represented by ballast stones. This solution, though widespread due to the ease of technological implementation, generates huge losses because a paved road without the installation of a geogrid or even a geotextile with separation role will degrade very quickly by incorporating large aggregates into the foundation earth. Practically, in order to ensure the feasibility of this technology, it is necessary to rebuild the stones at least once every two years.

An alternative is provided by non-standardized stabilization solutions. Non-standardized stabilizers can be classified (Scholen, 1992) into 2 groups: chemical stabilizers and puzzolan stabilizers.

Chemical stabilizers are also divided into five groups, namely: sulfonated oils, ammonium chlorides, enzymes, mineral bitumen and acrylic polymers.

This paper is intended to be a plea for the use of enzymes as stabilizers. Enzymes are non-polluting organic substances that act on the adsorption complex and help to obtain a denser structure of the compacted soil by increasing the electrostatic forces of attraction between the clay particles.

3. What Are Enzymes?

Enzymes are protein macromolecules presenting all the physical-chemical properties of this class of biomolecules: solubility, osmotic and diffusion properties, ion exchange, cracking, etc.

The basic function of enzymes is the catalyst in biochemical reactions that take place in the cells of living beings. From this point of view it should be mentioned that each biochemical reaction corresponds to an enzyme specific to them and only to them. This specialization is also due to the "sequential" make up of enzymes as well as the arrangement of the proteins that make them up in a unique spatial form to each of them. This spatial structure with 1Å distances "forces" the combination of two molecules that could not react due to their large distances and particularly attractive forces of attraction.

Practically, an enzyme-stabilized earth is a "béton clay". As with concrete, it is a mistake to use binder (in our case clay) without aggregates (in this case particles ranging from dust to gravel). The issue of granulometric distribution will be treated separately, but it is important to remember from the point of view of the problem treated in this chapter, as the class of cement radically influences the class of béton, similarly the activity index of the clay influences the mechanical properties of the stabilized earth.

From the point of view of the operating principle of the clay binder, by adding enzyme products, water is not removed as it might mistakenly be believed. What is achieved, however, is its better "fixation" in the adsorption complex by increasing the clay-cation particle-clay particle interaction forces.

3.1. Phases of enzyme stabilized mixtures

1. *Phase 1 – chemical cracking and mechanical homogenization*

This phase begins with the dilution of the enzyme mixture with water and its application to the soil mass. Tests have been made to determine the flow limit using solutions prepared locally and solutions prepared more than 24 hours before without any differences in the results. It can be concluded that by dissipating the enzymatic mixture in water it reaches a metastable state almost instantaneously.

The solution is applied to the previously comminuted soil several percent under the optimum compaction humidity. At this stage when applying the solution, it will be distributed in the mass of the earth in the same way as water would be distributed without addition, that is, by matrix suction of the earth (Fig. 1).

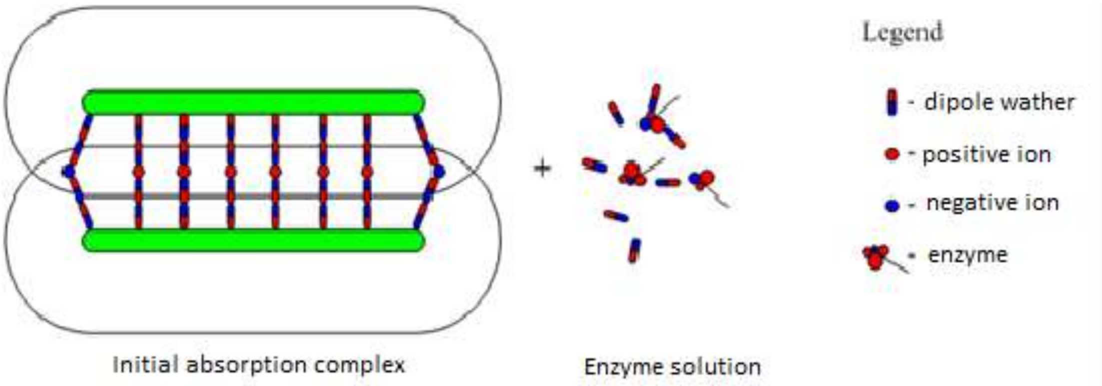

Fig. 1: Chemical cracking and mechanical homogenization

2. *Phase 2 – osmotic, electrostatic and rebalancing concentration*

These phenomena can also easily be highlighted by changing the behaviour of the earth over time. Thus, up to 30 minutes after the application of the solution, the soil becomes less “workable”, which can be felt if the material is homogenized at this time for the determination of the flow limit with the Casagrande cup. If, for example, a Proctor test is being carried out and the soil is left for more than 12 hours, its cohesion will make it very difficult to extract the material.

In this phase there is a movement of water (osmosis) and cation (electrophoresis) dipoles due to simultaneous electrostatic (Coulomb) and concentration (Fick) gradients (Fig. 2).

Here there is a huge difference between laboratory and field results. In the case of an electrostatic imbalance due to small particles (e.g. Na ion), their electrophoresis will be perfectly possible because, dimensionally, the ion can pass from a complex of adsorption of one clay particle to another without encountering large mechanical resistances from polarized water. In the case of protein macromolecules, this displacement under the concentration gradient is virtually impossible due to both their huge dimensions compared to the isolated ion and the multiple and much larger electrical charges that transform the macromolecule into a “scale”.

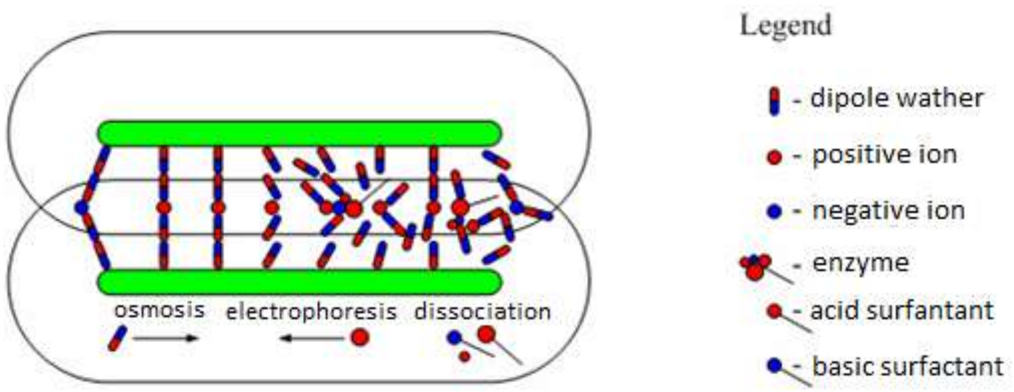

Fig. 2: Osmotic, electrostatic and rebalancing concentration

In the laboratory, controlled homogenization leads to a good dispersion of the additive that only re-balances the system electrostatically over short distances, while on the ground, this homogenization depends on the technology used.

Laboratory tests have shown that optimal soil compaction humidity is smaller (depending on the nature of the soil) than that of the earth with enzyme solution. This comes in support of the technology because in the first phase, immediately after applying the solution, the soil will behave as if there was no additive. So if the amount of water required to supply the optimum soil compaction moisture + solution is sized, it will be more lucrative in the first phase, which will favour electrostatic and chemical rebalancing phenomena.

3. ***Phase 3 - recovery of the colloidal system***

Characteristic of this phase is that cationic molecules no longer migrate between the adsorption complexes of the clay particles but only within the same complex. This phenomenon is accompanied by the polarization of water dipoles which rebuild the clay-cation particle-specific clay interaction chains. From a colloidal point of view, it is the time when soil-type dispersion systems turn into coagulated gel systems. This process lasts for 12-36 hours depending on the activity of the earth. Mechanical features improve asymptomatically until the maximum value is reached. Until equilibrium humidity is reached (over a period of several days), migrations of water dipoles under an osmotic gradient, reduced in magnitude, will not occur which will not influence the mechanical properties of the treated earth.

3.2. Laboratory data - the compressibility and permeability of the soil under the influence of the enzyme solution PERMA-ZYME11X

In order to highlight the influence of enzyme mixtures on different types of soil, mechanical tests were carried out on the following three types of soil:

- Ground 1: Red argent powder from Constanta harvested at -4.00m;
- Ground 2: Sandy clay dust collected from the foundation ground of DN1A, km 97+602;
- Ground 3: Cedar sand by Comarnic.

From the granulometric point of view, the three earths have the distribution shown in the figure below. By choosing the three types of soil it was desired to cover a granulometric field including non-cohesive soils to confirm the influence of strict enzyme mixtures on the adsorption complex soil (Fig. 3).

The soils were treated with a 1:10000 enzyme solution. This concentration is recommended by most manufacturers of enzyme mixtures for the practical application of the solution.

Compressibility has been studied by performing compression-compression tests on three soil samples taken from each earth, flooded with water, and three natural soil samples flooded with enzyme-based solution. The results of these tests as well as the average experimental curves are shown in the following figures (Fig. 3-5):

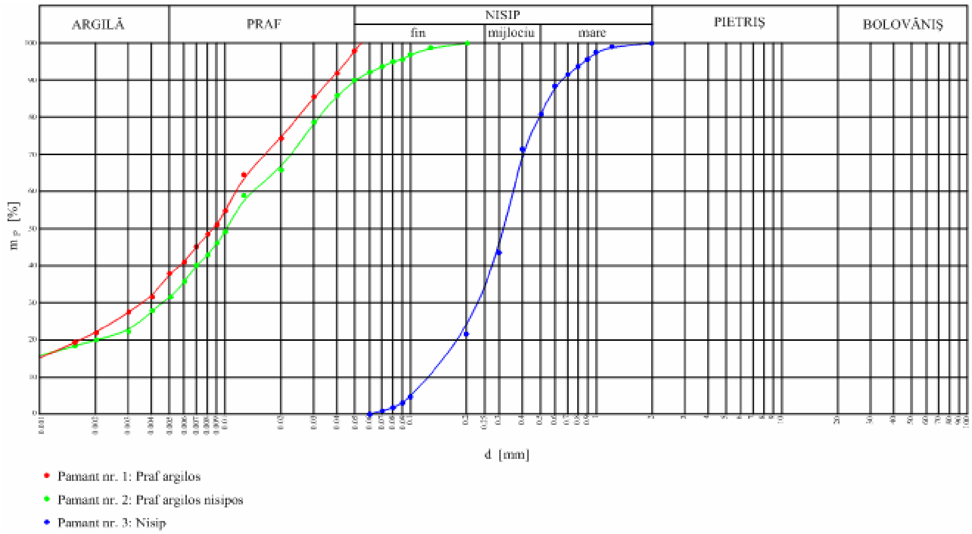

Fig 3: Compressibility and permeability of the soil under the influence of the enzyme solution PERMA-ZYME 11X

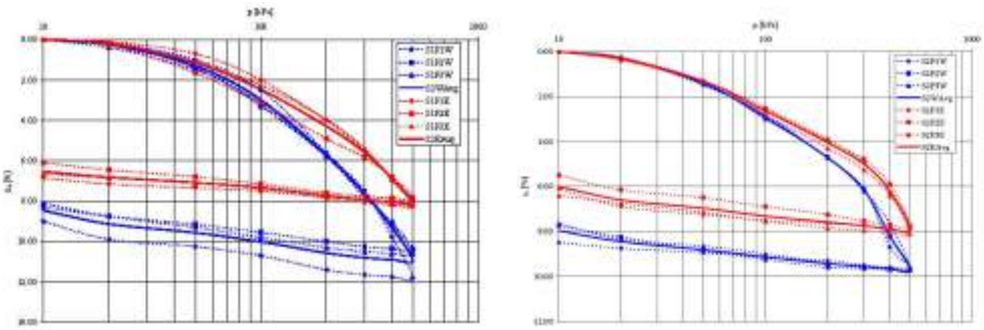

Fig. 4: The compression curve for soil compaction 1 and 2

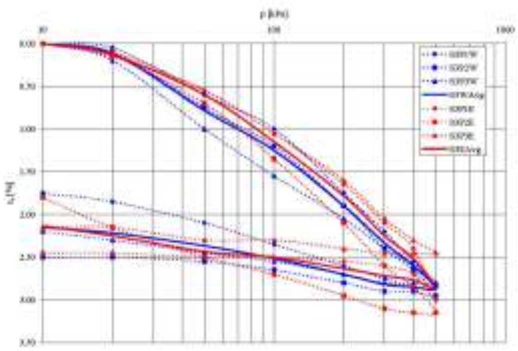

Fig. 5: The compression curve for soil-compaction 3

Influence of enzyme stabilization on compaction characteristics and bearing capacity of the soil

Based on the results presented in the previous paragraph that highlighted the feasibility of enzyme stabilization, they were chosen to study the compaction characteristics and soil bearing capacity of enzymes stabilized by two other soils (Fig. 6), namely:

- Ground 4: Yellow loessoid yellow Fetesti powder;
- Ground 5: Bloody clay reddish-brown of Jidvei;

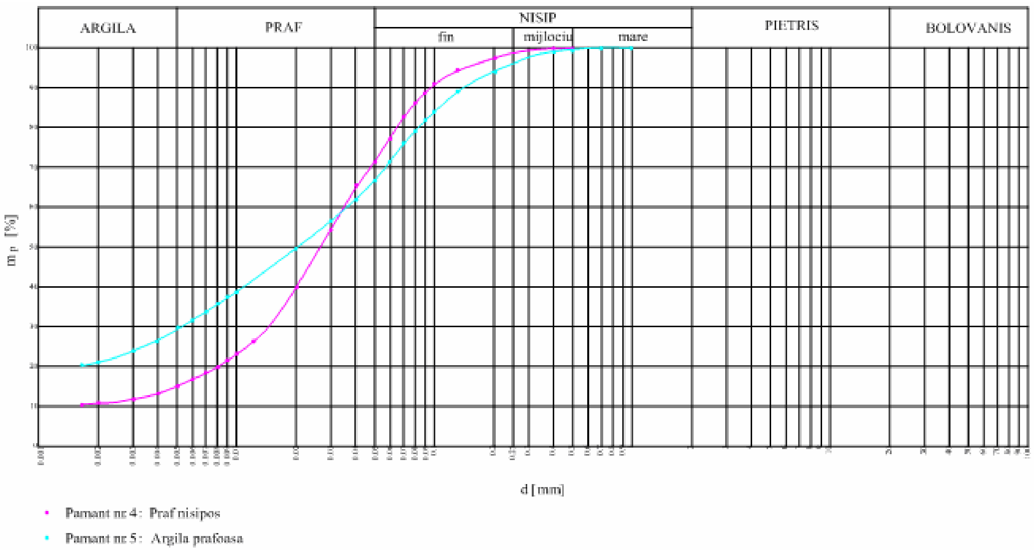

Fig. 6: Granulometric distribution of P4 and P5 soil

In the first phase the variation of the plasticity limits with the enzyme concentration was determined. The results obtained are presented in the figure below. To determine this variation, only soil and water were used initially with different enzyme concentrations (relative to dry solids) as follows: 1: 50000 (20ppm), 1: 25000 (40ppm), 1: 10000 (100ppm) and 1: 5000 (200ppm).

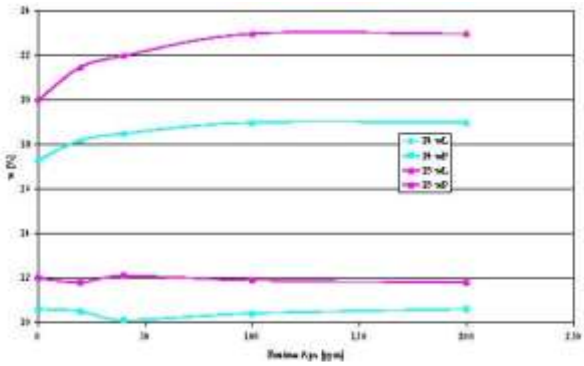

Fig. 7: Variation of plasticity limits with enzyme concentration

CBR tests were performed according to US standards ASTM D1883-99 in parallel with the modified Proctor test. This set of determinations was performed on ground water samples and on ground samples mixed with enzymes in a dry weight ratio of 1: 50000 (20ppm) and 1: 25000 (40ppm). On each sample compacted to a certain humidity, the CBR test was performed.

The results of the Proctor test on the P4 and P5 lands can be found in the figures below:

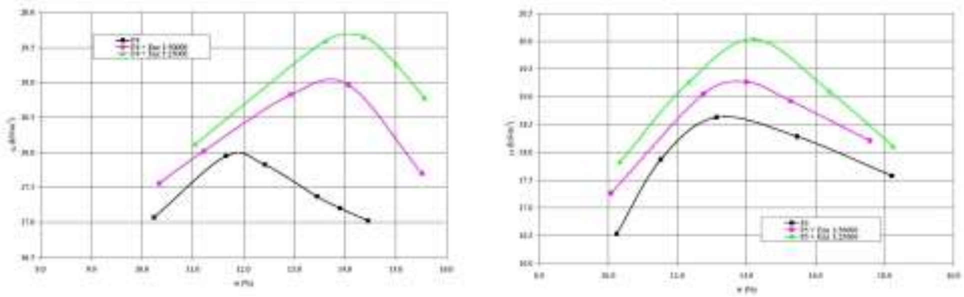

Fig. 8: Proctor tests on P4 and P5 soil

The variation of compaction parameters with the enzyme concentration for P4 and P5 soils is represented in Figures 9 and 10.

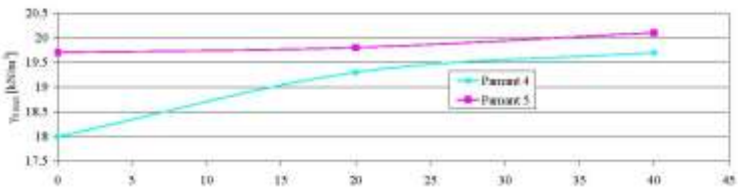

Fig. 9: Concentration Enzyme: water [ppm]

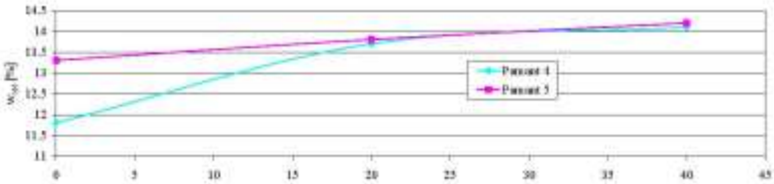

Fig. 10: Concentration Enzyme: water [ppm]

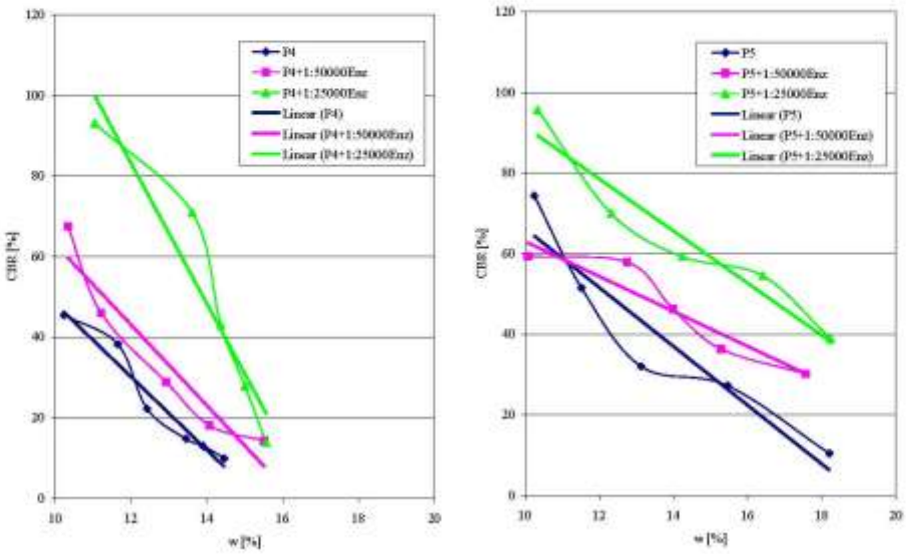

Fig. 11: Variation of CBR with Humidity for Different P4 and P5 Stabilization Recipes

The above graphs represent the variation of the CBR index with the moisture for the two stabilization recipes (1:25000 and 1:50000) compared to the results obtained for the untreated soil.

Based on the experimental results presented, it is very clear that for treatment with the enzyme solution the P1 and P2 lands reduce their compressibility about 30% and the permeability coefficient decreases approx. 3 times. The influence of the studied product is virtually nil in the case of non-cohesive earths.

By comparing the values obtained at the compaction it is noted that some soils, although having the more developed adsorption complex (slurry clay), may be less susceptible, from the point of view of compacting, to stabilization with enzymes than others with a complex of adsorption much less developed (sandy dust). This can be explained by the fact that the electrostatic deficiency of the clay is much lower than that of the sandy dust.

The addition of enzymes has been felt significantly over the flow limit values and absolutely insignificant on the kinetic limit values. This confirms that enzymes do not have a direct role in improving the physico-mechanical properties of the earth, but indirectly by acting on water in the adsorption complex. It can also be noted that beyond a certain limit of about 1:10,000 (100ppm), supplementation of the amount of enzyme no longer has any measurable effect on the adsorption complex. For both earths the increase in the value of γdmax increases also the value of the optimal compaction humidity, which is due to the fact that there is an increase in the number of water-dipole "electrostatic bridges" and does not occur, as it is currently believed by removing water from the ground.
Practically, with the addition of enzymes, the soil is brought to the maximum of its compaction capacity. From concentrations greater than 1:25,000, the solution becomes too expensive for a small improvement rate.

In terms of load capacity, the compaction supplement leads to a clear improvement in the values obtained on treated land versus untreated land. It can be noticed that with the increase of humidity, the less cohesive lands show a convergence of the results due to the increasingly strong manifestation of the non-cohesive character of the material (by weakening the cohesion forces between the fine parts), whereas for the plastics there is a divergence of results. Divergence is due to the fact that a saturated cationic adsorption complex retains its interaction forces over a much larger distance between particles than an unsaturated one.

3.3. Technology of application of the PERMA-ZYME 11X enzymatic solution in road construction

Preparation of the ground road bed for the start of the actual commissioning works. Determining the type of soil - can treat cohesive lands with a clay content of 15-25% (Fig.12).

Fig. 12: Preparation of the ground road

If this percentage is lower, we must add clay until the optimal percentage is reached.

– Laboratory determination of optimal soil compaction humidity;
– Determining the volume of land to be stabilized (for each 33 cubic meters of material, 1 litre of PERMA-ZYME11X is required)

Example of calculation of the enzymatic solution required for 1 km of road:

The width of the road	6.00 m
The length of the road	1000 m
Thickness of the stabilized layer	0.15 m
Total volume to stabilize	900 mc
Cubic meters of soil / litre PERMA-ZYME11X	33 mc
The total amount of PERMA-ZYME11X	22.27 l

Calculation of the amount of water to be added to obtain the optimum compaction humidity:

Density of soil	1.602
Optimal compaction humidity	12%
Moisture determined in the laboratory	8%
Moisture added (12% -8%)	4%
The amount of added water / mc (1,602x4%)	64,08 l
The total amount of water needed / mc (64.08x0.9)	57.672 l

The equipment necessary for the application of the execution technology are:
- Autogreder - earthworks preparatory work;
- Cold Recycling Machine;
- Water tank;
- Roller or plain roller compactor.

The execution of a Category II-V category road in PERMA ZYME technology has the following stages (Fig. 13):

– It is sacrificed and the soil layer is being thawed, and it should be taken into account that the successive layers have a maximum of 20 cm each;

– Prepare the optimal dosage according to the manufacturer’s recommendations, 1L PERMA-ZYME11X and 5,00 to water at 33 cm of soil to be stabilized. For cohesive earths with a clay content of 15 ... 25%, the optimum compaction humidity is between 9 ... 14% according to the standards in force. In the case of sprinkling with a tank, mixing the soil with the solution is done with a mechanical cutter until it becomes homogeneous. The road can be opened after 72 hours of treatment. For land roads, re-routing is recommended, sometimes with the addition of stony material and optimal solution dosing so that the total moisture does not exceed the optimum moisture content.

– After creating the cross-sectional slope for water drainage, the material initially treated with roller compactors with metallic wheel tire is compacted. The number of passages is determined experimentally to ensure the degree of compaction projected. For a suitable compacting, the recommended level is min. 92%.

Fig. 13: Execution technology with PERMA-ZYME11X

Technical characteristics of the stabilized earth layers with PERMA-ZYME 11X

Characteristics	*UM*	*Recommended values*
Resistance to compression (after 28 days)	N/mm^2	min.1,5
Mass loss (freeze-thaw)	%	max.7
Coefficient of permeability	cm/s	max.0,08 x 10-8
Load capacity (Benkelman lever deflection measurement)	1/100 mm	max.250

Conclusions

In order to draw some conclusions, I want to analyze in parallel the classic design and construction solution for ballast and stone road Sparta vs. the unconventional solution with PERMA-ZYME11X.

The execution of a category II-V road in PERMA-ZYME11X versus classical technology has the following stages:

<table>
<tr><th>Enzymatic Solution</th><th>Classical Solution</th></tr>
<tr><td>➢ Removing the plant layer (if applicable)</td><td>➢ Removing the plant layer (if applicable);</td></tr>
<tr><td>➢ scarification of the soil in depth depending on the road category and the requirements of the beneficiary;</td><td>➢ scarification of the soil in depth depending on the road category and the requirements of the beneficiary;</td></tr>
<tr><td>➢ making a homogeneous blend of the stabilized layer with the PERMA ZYME 11X enzymatic solution;</td><td>➢ transport and storage of granular material from the ballast</td></tr>
<tr><td>➢ cross-sectional profile;</td><td>➢ transport and storage of granular material from broken stone</td></tr>
<tr><td rowspan="2">➢ compacting the road to a compaction level of over 92% and maturing in 72 hours</td><td>➢ cross-sectional profile;</td></tr>
<tr><td>➢ compacting the road to a compaction degree of over 92%;</td></tr>
</table>

Advantages / disadvantages of implementing projects with unconventional / classic solution:

Enzymatic solution with PERMA-ZYME11X	**The Classic Solution (broken stone, ballast)**
• It involves a low consumption of materials and energy;	• It involves a large volume of relocated materials, shipment from the bilge-yard, which implies a higher value;
• 100% ecological, zero impact on animals, fish or vegetation and is completely biodegradable;	• Negative impact on the environment and human settlements through high levels of pollutants;
• It provides a higher net guarantee than the classical solution -10 years;	• Destruction of existing infrastructure with heavy-duty transport equipment;
• The shorter execution time can also reach 75% less than ballast and crushed rock;	• High execution time;
• Low cost of work;	• High cost of work due to the large number of machinery and human resources;
• There is no red line in the locality, ensuring good access management;	• In the locality the red line rises due to the classic stratification (ballast and broken stone - at least 45cm), this implies a discomfort for the locals on the access side. If the current red line is preserved, additional excavations will be carried out involving a higher price.
• Natural resources are used from the soil	• High consumption of granular material (ballast and broken stone)
• Reduces maintenance costs;	• Requires regular maintenance if it does not pave
• Execution time of about 4 days (1 km of road), of which 3 days maturation of the surface treated with enzyme	• Execution time of approximately 20 days (1 km of road);

In conclusion, I would like to highlight the technical and economic benefits of the PERMA-ZYME11X solution to encourage the implementation of such projects in ROMANIA:

- ✓ Increasing compression resistance: The enzyme acts as a catalyst for accelerating and reinforcing the adhesive in road material. The enzyme creates a dense, cohesive, and more stable soil.
- ✓ Reduce compaction effort and improve soil workability: lubricate soil particles. This makes the soil easier to improve and allows the compactor to reach a desired soil density with fewer passages.
- ✓ Increased soil density: helps to reduce the gaps between soil particles by altering the electrochemical attraction in soil particles and releasing water. The result is a tighter, drier and denser road foundation.
- ✓ Reduces water permeability: a tighter soil configuration reduces water migration, which normally occurs in the voids between the particles. It produces greater resistance to damage by penetrating water in conjunction with freeze-thaw phenomena.
- ✓ Minimizes the loss of surface materials (gravel, soil, etc.) of roads due to erosion or abrasion through traffic.
- ✓ Minimizes production (environmentally damaging) and the use of crushed rock and / or classical mineral stabilizers in road construction and maintenance.
- ✓ Reduces fuel consumption associated with repairs frequencies within the same time frame.
- ✓ Eliminates the impact of gravel mills and open pits. PERMA-ZYME 11X.
- ✓ Improves structural integrity, load capacity and reduces serious defects such as holes and cracks, resulting in lower maintenance costs and increased comfort.
- ✓ Strengthens base layers and form layers in the road structure to build or restore rural, forest, national or highway roads.
- ✓ Reduces the consumption of aggregates and fine particles and reduces dust formation.
- ✓ It results in significantly longer durability and longer life areas for secondary roads.

R E F E R E N C E S

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